Chapter 8 GOMS Analysis

The original research description called for a CPM-GOMS analysis due to the highly parallel nature of virtual environment interaction. CPM-GOMS divides task execution into three parallel tracks based on the perceptual, cognitive, and motor functions involved. However, further investigation of the goals of this work as well as the available data lead to the conclusion that CPM-GOMS would not be an effective method of analysis due to two primary factors: 1) CPM-GOMS does not provide a mechanism for selection rules or criteria. Selection alternatives were found to be the bulk of the data taken from the verbal protocol and had to be accounted for. 2) This research is focussed on the cognitive aspects of the task (i.e. wayfinding more so than navigation) rather than the perceptual or motor. Therefore, a CMN-GOMS analysis was concluded to be the most practical alternative to show the cognitive activity involved in wayfinding tasks performed in this experiment. Furthermore, the analysis has been performed at the functional level in order to capture the conceptual problem solving behavior without the low-level details of its actual execution which would necessarily include heavy doses of motor functions.

An essential fact regarding the nature of this analysis is that CMN-GOMS is used here as a notation by which we can view the execution of a primarily cognitive task. It is <u>not</u> intended to be used for predictive purposes or as a model of expert behavior. Consequently, there are notable differences between this analysis and a traditional CMN-GOMS analysis (Card, Moran & Newell, 1983) which will be described later.

Being a cause-and-effect experiment, an inductive method of analysis is appropriate (Patton, 1984). Although certain aspects of the experiment were anticipated to hold to expectations, no hypotheses were made as to the actual behavioral effects expected to be observed or even that any effects would exist at all. Due to the limited number of subjects, a negative case analysis and hypothesis generation (Kidder & Judd, 1986) was used within the CMN-GOMS analysis to formulate a working hypothesis (generalized methods and selection criteria) throughout the investigation. This technique requires that behaviors exhibited by all subjects be represented in the final analysis. As negative cases arise which contradict the working hypothesis in any way, the hypothesis is altered to encapsulate those behaviors. This allows the use of within-subject measures which was essential to the success of this study. This technique requires fewer subjects and enables effective control of individual differences.

For the purposes of this analysis, wayfinding tasks in general have been broken into their primary components as shown in Figure 8-1. Navigators must first ground themselves in the virtual world by acquiring their orientation and position. Then, they begin to undertake the explicit tasks of five naive searches followed by one primed search. If at any time they lose their orientation or position, they must reacquire it before proceeding. Also, during task execution, actions may be taken which are specifically meant to help the navigator maintain orientation and position and consequently, to develop a better cognitive representation. Finally, as targets and objects of interest are located in the world, they are explicitly placed into memory so that they may be recalled later for the map drawing exercise.

The basic task-level description does not include those components outside of the explicit task as they may not be required for successful task completion.

```
goal: search/explore-virtual-world          ; unit task level description
.  goal: acquire-orientation                ; orientation and position are
.  goal: acquire-position                   ; tightly coupled
.  goal: naive-search                       ; five of these followed by
.  goal: primed-search                      ; one of these
```

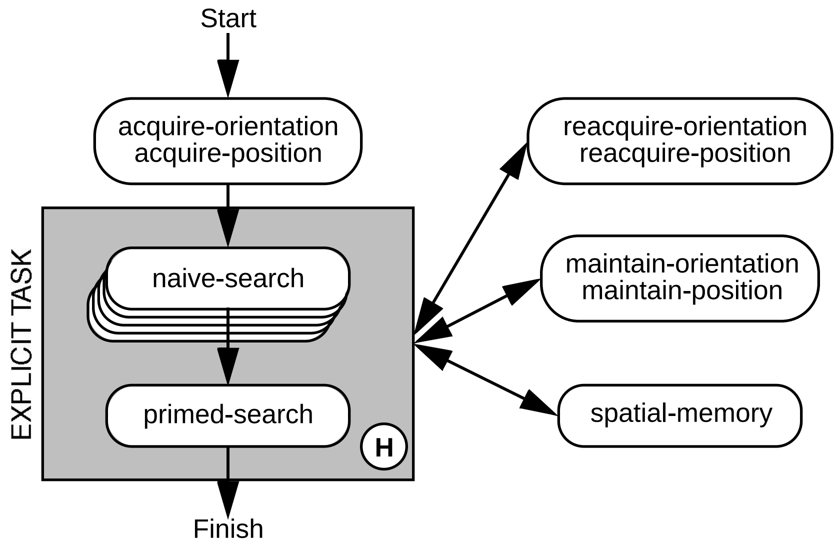

Figure 8-1 High-level schematic diagram of task execution used in the CMN-GOMS analysis. The H designates a history mechanism by which any arc traversed out of the gray, explicit task nodes returns to the node of departure.

However, each of the aforementioned elements of the task will be analyzed in its entirety within the context of the overall task in the following sections.

This linear description does not accurately show the flow of execution. Unlike most computer system tasks typically analyzed with GOMS, the subject may choose more than one method to achieve a goal. For example, when using a word processor, there are typically at least two ways to change the style of the selected text; either via the pull-down menu or using accelerator keys. Either method is acceptable but the subject will never use both in a single execution sequence. In the type of tasks to be analyzed here, there are also several acceptable methods available to complete any task, but it *is* feasible to choose more than one method for any given instance. An example of this would be orienting the viewpoint within the map/grid treatment. A subject may first align the view with the edge of the map. Then, the post that coincides with that edge may be identified and used as a reference point. The post method was unnecessary in light of the first action. However, this type of reinforcing or repetitive behavior is the rule rather than the exception in this analysis.

The overall goal of all strategies described in this chapter is to enable an efficient search to locate all five targets and afterwards, the home target, while maintaining orientation in order to draw an accurate map of the environment after completion of the task. The interest of this data to this research lies in the notable differences in behavior and in search strategies based on the navigation aids provided (or not provided as the case may be). Therefore, the details of each subtask will be enumerated for each treatment in the experiment. Note that although the experiment included only ten subjects, many subjects used several techniques during any one trial as they discovered better alternatives or found their current approach ineffective. Consequently, this analysis is meant to be purely qualitative in nature offering little information as to the number of subjects employing any one technique. General frequency of use is mentioned, however, as it lends support to the notion of an intuitive plan of action. Selection criteria have been specified only for those cases where they are clearly defined. Most commonly, subjects selected a method based on intuition restricted by the cues and information currently perceived or available.

The Control Treatment

Due to the lack of cues available for use in navigation, task execution in the control treatment is extremely unstructured. There were several subtle cues which could be found to be effective if used appropriately. Many subjects were unable to detect them or to see their potential value. This fact is reflected in the wide range of performance levels found in this treatment.

As always, the first action subjects take is to ground themselves in the virtual world. They attempt to develop a coordinate system (often merely conceptually) by which to orient themselves and the targets they will find. Since this coordinate system is not given in the control treatment, it must be determined on an individual basis.

goal: acquire-orientation	*; always relative to some object*
. **[select goal:** set-bearing-to-home-method	*; world orientation aligned with*
. . . orient-with-respect-to-home-target	*; home target orientation*
. . . align-world-to-home-target-orientation	*; home often used as only cue*
. **goal:** set-bearing-default-method	*; commonly used*
. . . orient-with-default-view-direction	*; similar to set-bearing-external*

. .	. initial-view-direction-is-north	*; assume cardinal directions* †
.	**goal:** set-bearing-to-landmark-method	*; if land is visible from home*
. .	**[select goal:** nearest-land-method	*; if no landmark is available*
. . .	. orient-toward-shortest-path-to-land	*; infer direction to nearest shore*
. .	. **goal:** geographical-landmark-method	*; if a landmark is available (rare)* *; infer direction to the landmark*
. . .	. orient-toward-nearest-geo-graphical-landmark**]**	*; from the home target*
.	**goal:** set-bearing-external-method	*; i.e. in physical space*
. .	. ground-body-externally	*; a foot in this case*
. .	. orient-with-respect-to-the-body	*; does not require reacquisition*
.	**goal:** set-bearing-to-edge-method	*; often used with set-bearing-to-*
. .	. move-to-any-edge	*; texture*
. .	. **goal:** determine-direction-of-edge-method	*; an approximate method*
.	**goal:** set-bearing-to-texture-method	*; texture does not necessarily*
. .	. **goal:** obtain-maximum-altitude-method	; *follow cardinal directions*
. .	. orient-towards-texture-patterns**]**	

Because there is no absolute information to go by (e.g. a sun) subjects based all judgments on relative information. The first two described methods were also the most commonly chosen ones (See Figure8-2). The set-bearing-to-home-method involves aligning the home object to the world. In Figure 8-2, A is an example of this form. As described in Stimuli and Apparatus on page 104, all targets were rotated some random amount so as not to provide absolute directional information. However, with little else at their disposal, many subjects attempted to do this. If this technique was later combined with any edge-following techniques (described under naive-search), there would certainly be a conflict as the subject's conception of direction conflicted with actuality.

More commonly, subjects would state, "I guess one direction is as good as another." and would consequently use their original view direction as "north" or "up". This is shown as B in Figure 8-2. This is further illustrated by the fact that the majority of subjects drew their maps oriented in the same direction with their original, default view direction as north (See Table8-1). Most subjects frequently used the familiar directional terms

† The term "cardinal directions" refers to the dominant absolute directions humans (within our culture) are most familiar with; north, south, east, and west.

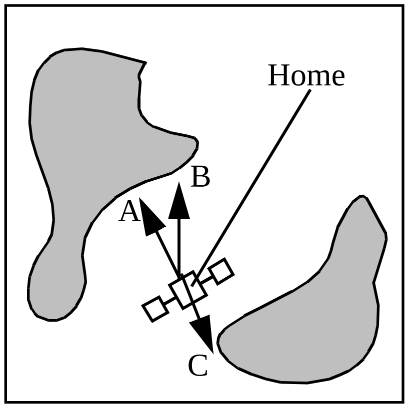

Figure 8-2 Examples of acquire-orientation. (A) set-bearing-to-home (B) set-bearing-default (C) set-bearing-to-landmark

"north", "south", "east", and "west" in describing where they were or where they were going. For this reason, the cardinal directions will be used within this analysis but only as an indicator of the use of an absolute directional system.

Subject	S1 ←	S2 ←	S3 ←	S4 ←	S5 ←	S6 ←	S7	S8 ←	S9	S10 ←	%
Control	←	←	←		←	←	← ←		← ←		80
Map	←			←			←	←	←	← ←	70
Grid	←	← ←	←	←	← ←	← ←		←		←	40
Map/Grid			←	←			←	←	←		50

Table 8-1 The drawn map orientations are shown as arrows. An upward arrow indicates that the map was aligned with the initial view direction. The percentage of these subjects is shown in the final column.

If it was possible to see any land from the home position, the subject may have chosen to orient relative to that land mass. In some cases, the point of reference was a general land mass while in others, it was a specific geographical landmark. In Figure 8-2, example C shows a reference point on the land mass used for direction. The term "geographical landmark" will be used extensively in this and the following sections. It is defined here as a unique topographical or configurational structure within a body of terrain. Most commonly, this is a bay, peninsula, or particular point which the subject determines can be reidentified if necessary. This technique was relatively rare in the control treatment as subjects frequently noted how few land configurations were suitable for use as landmarks.†

Subjects who used this technique also used the edge-following search method. Presumably, these subjects placed their focus of attention on the land masses as a likely source of successful searching.

A technique used by one subject was to orient via an external source. He grounded one foot in the original view direction so that it could always be recovered instantly via his kinesthetic sense. This subject clearly maintained his orientation throughout the treatment as reacquisition was never needed. However, note that while this technique is very effective in providing the subject with a sense of direction, it provides no assistance in determining a sense of position.

The last two methods were extremely rare primarily because they were either ineffective or difficult to use in providing assistance. The first involves locating an edge of the world and using it to determine orientation. This is difficult if not impossible as the edges have no visual cue to mark them (See Stimuli and Apparatus on page 104). This technique requires another subtask to determine the direction of a detected edge.

goal: determine-direction-of-edge-method
. repeatedly-collide-with-edge *; may be confounding if in corner*
. align-viewpoint-with-edge

The subject must repeatedly bump the edge in order to determine its direction. If the subject happens to be in a corner and is bumping two edges, this task is complicated significantly. Although the subtask is highly demanding, subjects who did choose to use the edges as cues were often able to eventually glean useful information. Subjects who used the set-bearing-to-edge-method of orientation were more likely to attempt to also use the sea texture as a cue.

These subjects noticed that from the maximum altitude, the pattern of the sea texture could be detected. They attempted to use the pattern as a guide of at least the cardinal directions. However, no subjects successfully used this technique to completion as they found the pattern to be ambiguous and not necessarily aligned with the cardinal directions

† This will not be the case when maps are used to provide a top-down view.

of the world. The maximum altitude was reached by movement in either a forward or backward direction. This, of course, was a side-effect of the locomotion metaphor chosen (See Stimuli and Apparatus on page 104).

goal: obtain-maximum-altitude-method
. **[select goal:** forward-method
. . . point-view-direction-up
. . . move-forward
. **goal:** backward-method
. . . point-view-direction-down
. . . move-backward**]**

Subjects found that the backward-method was preferable to the forward-method because the world could be kept in view during movement. The forward-method, on the other hand, requires that the subject lower the horizon out of view.

goal: acquire-position *; always relative to some object*
. **[select goal:** relative-to-home-method
. . . **goal:** dead-reckoning-method *; this distance used to estimate*
. . . infer-distance-from-home-target *; others*
. **goal:** relative-to-landmark-method *; if land is visible from home*
. . . **goal:** dead-reckoning-method *; target*
. . . **[select goal:** distance-to-nearest-land-method
. . . . infer-distance-between-home-and-nearest-land
. . . **goal:** distance-to-nearest-geographical-landmark-method
. . . . infer-distance-between-home-and-nearest-geographical landmark**]**
. **goal:** relative-to-edge-method
. . . **goal:** dead-reckoning-method
. . . infer-distance-from-nearest-edge**]**

In most cases, the acquisition of position is a counterpart to the acquisition of orientation; but not all. Also, all techniques require some use of dead reckoning which can be described as a subtask in this way:

goal: dead-reckoning-method
. remember-relative-direction
. move-straight
. move-constant-velocity
. estimate-time
. infer-distance-travelled

The subject must remember the relative direction of travel; i.e. relative to some reference point. Then, the subject must move in a straight line and at a constant velocity in order to estimate position at some future time. The environment, in turn, must supply some information as to the velocity of movement. In this case, the texture of the ocean surface is meant to supply this. However, many subjects commented that the intermittent lag in the frame rate and the associated discontinuity in perceived velocity caused them to lose their ability to judge distance. It is interesting to note that while subjects commented only on the effect of the lag on distance estimation, their ability to infer direction was much more profoundly affected (See Map Direction Error on page 127).

While the actual execution of a dead reckoning navigation technique in the real world is a complex and highly demanding skill, in the virtual world its precision may be lowered significantly allowing novices to execute it effectively. Results of this experiment indicate that the basic concept of dead reckoning is intuitive and well-understood although most subjects cannot actually define “dead reckoning” correctly. The fundamental relationship between space and time allows even the most unskilled subjects to mentally approximate position based on a known past location, a direction of travel, and a constant velocity.

For those occasions when subjects became disoriented (in the control treatment, they were often disoriented more than they were oriented), it became necessary to recover their grounding in the world in some way. A number of techniques were used, most of which have a close relative among the methods of orientation acquisition.

goal: reacquire-orientation	*; similar to acquire-orientation*
. **[select goal:** set-bearing-to-target-method	*; this may be the home target*
. . . bring-nearest-target-into-view	*; but not necessarily - the target*
. . . orient-with-respect-to-target	*; must be of known orientation*
. **goal:** set-bearing-to landmark-method	*; only if one has been pre-*

. .	. bring-landmark-into-view	*; determined*
. .	. orient-toward-geographical-landmark	
.	**goal:** set-bearing-to-edge-method	*; often ambiguous because*
. .	. move-to-nearest-edge	*; subject doesn't know if the edge*
. .	. **goal:** determine-direction-of-edge-method	*; runs N-S or E-W*
.	**goal:** set-bearing-to-texture-method	*; must be maintained throughout*
. .	. **goal:** obtain-maximum-altitude-method	*; search*
. .	. orient-towards-texture-lines**]**	*; viewed best from high altitude*

If the subject has been orienting relative to targets or to one specific target, then the most obvious method to reacquire orientation is to return to that target. The subject need not move all the way up to the target but only close enough to note its orientation. A more common method was to return to some landmark of known orientation for reference. This, of course, only applies if the subject has set a landmark which is reasonably close to the current position. Again, the landmark must have a specific, and known orientation. But as noted earlier, subjects seldom found useful geographical landmarks in the control treatment.

Subjects who found themselves in the outskirts of the environment (or at least what they thought was the outskirts of the environment) often tried to orient with respect to an edge. This method requires the determination of the edge's direction as described earlier but remains ambiguous due to the fact that the subject frequently does not know whether the edge runs north-south or east-west with respect to a Cartesian coordinate system.†

Lastly, sea texture was also used in orientation reacquisition but for the same reasons as noted earlier, it was ineffective. If texture is to be used for orientation, it must be maintained explicitly throughout the task. This is a highly demanding requirement which detracts heavily from the primary task of searching and therefore was always eventually abandoned.

Position is reacquired in methods mirroring those of acquisition. Remember that the subject is not only locating targets but is attempting to learn the structure of the space to

† I do not mean to imply here that all subjects who may have used this technique viewed the world in a N-S-E-W configuration.

draw a map. Spatial information learned while disoriented or displaced is virtually useless for this purpose.

```
goal: reacquire-position                                    ; similar to acquire-position
. [select goal: relative-to-target-method
. .         . goal: dead-reckoning-method                   ; this may require retrace-steps
. .         . infer-distance-from/to-nearest-target
.           goal: relative-to-land-method                   ; if land is visible
. .         . goal: dead-reckoning-method
. .         . [select goal: nearest-land-method             ; if no landmark is set
. . .                   . infer-distance-from/to-nearest-land
. .         .           goal: nearest-geographical-landmark-; requires that a landmark has
                              method                        ; been predetermined
. . .                   . infer-distance-from/to-nearest-geo-
                          graphical-landmark]
.           goal: relative-to-edge-method
. .         . goal: dead-reckoning-method                   ; requires movement to the edge
. .         . move-until-edge-is-detected                   ; since it is not visually marked
. .         . infer-distance-from-edge
.           goal: retrace-steps-method
. .         . goal: dead-reckoning-method
. .         . move-back-through-previous-movements]         ; until point is reached where
                                                            ; position is known
```

If the subject has passed a target of known position (i.e. the subject was able to place the target in a cognitive representation satisfactorily), that target can be returned to in order to regain positional information. If the subject must retrace a number of steps (more than one target), then the method is referred to as retrace-steps-method. This same technique can be used if a geographical landmark has been set or if the subject is using edges as references. Note that for all these techniques, dead reckoning is used to estimate the distance to or from a known position. As referred to earlier, the dead reckoning occurs implicitly as the subject is basically unfamiliar with the concept yet intuitively is able to execute it.

Most subjects (not all) understood the difficulties they would face if they became disoriented. These subjects undertook steps to maintain their orientation and position. These methods are related to but different from those which are taken if orientation or position are lost and must be reacquired. In this case, the subject is properly oriented but is executing extra steps to properly orient either themselves or a target in the environment.

```
goal: maintain-orientation
. [select goal: return-to-previous-target-method
. .         . move-back-to-last-target
. .         . infer-direction-from-target-as-reference
.           goal: move-between-targets-method         ; if targets are spatially close
. .         . move-between-targets                    ; so that both are visible
. .         . infer-direction-from-two-targets        ; rather than one
.           goal: return-to-geographical-landmark     ; if a landmark has been pre-
. .         . move-to-landmark                        ; determined
. .         . infer-direction-from-landmark-as-reference
.           goal: bump-edge-method
. .         . move-to-nearest-edge
. .         . goal: determine-direction-of-edge-method
. .         . infer-direction-from-edge-as-reference
.           goal: set-externally-method
. .         . reorient-with-respect-to-body-position]
```

Subjects who attempted the graph-method of spatial memory (See spatial-memory on page 148) usually tried to orient with respect to the nodes in the graph (the targets). Therefore, they would either move all the way back to the previous target to infer its relative direction from the new location, or they would move in between the two targets so that both were visible for the same reason. Similarly, if the subject was using an edge-following search technique (See naive-search on page 150), it may be necessary to return to a geographical landmark on the land mass to determine orientation. Subjects searching on the periphery of the world often attempted to determine how close to the edge they were and what direction that edge extended. Finally, the subject using an external orientation method oriented himself and targets relative to his body's posture.

Along with each of these orientation maintenance methods is a corresponding position maintenance method with one exception; there is no way to use an external method to determine position.

```
goal: maintain-position
. [select goal: return-to-previous-target-method
. .         . goal: dead-reckoning-method
```

```
. .       . move-back-to-last-target
. .       . infer-distance-from-target-as-reference
.         goal: move-between-targets-method
. .       . goal: dead-reckoning-method
. .       . move-between-targets
. .       . infer-distance-from-two-targets
.         goal: return-to-geographical-landmark
. .       . goal: dead-reckoning-method
. .       . move-to-landmark
. .       . infer-distance-from-landmark-as-reference
.         goal: bump-edge-method
. .       . goal: dead-reckoning-method
. .       . move-to-nearest-edge
. .       . goal: determine-direction-of-edge-method   ; necessary to know which edge
. .       . infer-distance-from-edge-as-reference]     ; has been intersected
```

The subject using an external orientation method used dead reckoning between targets to form a graph. He could have used any of these but followed the method most closely aligned with his cognitive representation. While a subject may be determining orientation information from located targets, position information is also available via dead reckoning. The same is true for geographical landmarks and world edges if in use.

The next subtask, spatial-memory, refers to the mental representation the subject is using to remember spatial information and the cognitive task of extracting and storing that knowledge. This was not an explicit part of the overall task but was necessary if the subjects were to render a relatively accurate map of the world on completion of the search tasks. See also Figure 8-3 for a pictorial description of each method.

```
goal: spatial-memory                            ; how spatial info is memorized
. [select goal: graph-method                    ; associated with local-search
. .       . located-targets-as-nodes
. .       . paths-between-targets-as-edges
.         goal: grid-method                     ; associated with lawnmower-
. .       . world-to-cartesian-space            ; method
. .       . targets-mapped-relatively           ; conceptually up/down/across
.         goal: object-anchor-method            ; associated with edge-following
. .       . targets-located-relative-to-land    ; and multi-pass-methods
.         goal: sweep-method                    ; associated with extent-method
. .       . targets-located-relative-to-edges]
```

The graph-method places found targets as nodes in a graph with the paths between them as edges in the graph. Edges between nodes of which the subject has not traversed the path must be inferred. Subjects who used local searches around land masses and other targets tended to use this representation.

The world can also be viewed as a square grid of some arbitrary resolution. The shape of the grid is clearly influenced by the shape of the world. In other words, had the world been round, a radial grid may have been used. This method was used with the back-and-forth lawnmower-method of search to be described later.

Subjects using a search technique based on the coastline of the land masses anchored targets relative to the land masses wherever possible. Lastly, when the world edges were used to search the extents of the environment, targets were placed relative to the edges.

The method of search each subject chose to accomplish the given task was always related to one of the representations described above. This is true for both the naive searches and the primed search alike. See Figure 8-3 for a pictorial description.

goal: naive-search		
. **[select**	**goal:** local-search-method	
. .	. search-local-space-to-target/landmark	*; for each target found*
.	**goal:** lawnmower-method	
. .	. locate-any-corner	*; of known orientation*
. .	. move-across-world-to-opposite-edge	*; one up-down sweep*
. .	. move-across-world-one-step	*; one step = view depth*
. .	. repeat-until-entire-world-searched	
.	**goal:** edge-following-method	*; single circuit method*
. .	. locate-land-mass	
. .	. select-geographical-landmark-on-coast	*; needed to determine circuit*
. .	. traverse-edge-until-landmark-revisited	*; one time around*
.	**goal:** multi-pass-method	
. .	. locate-land-mass	*; same as above*
. .	. select-geographical-landmark-on-coast	
. .	. traverse-edge-until-landmark-revisited	*; clockwise/counterclockwise*
. .	. move-further-from-coast	*; similar to a step as above*
. .	. repeat-until-other-land-mass-located	*; or this land no longer in view*
.	**goal:** heuristic-method	*; often used with other methods*
. .	. intensify-search-around-land	

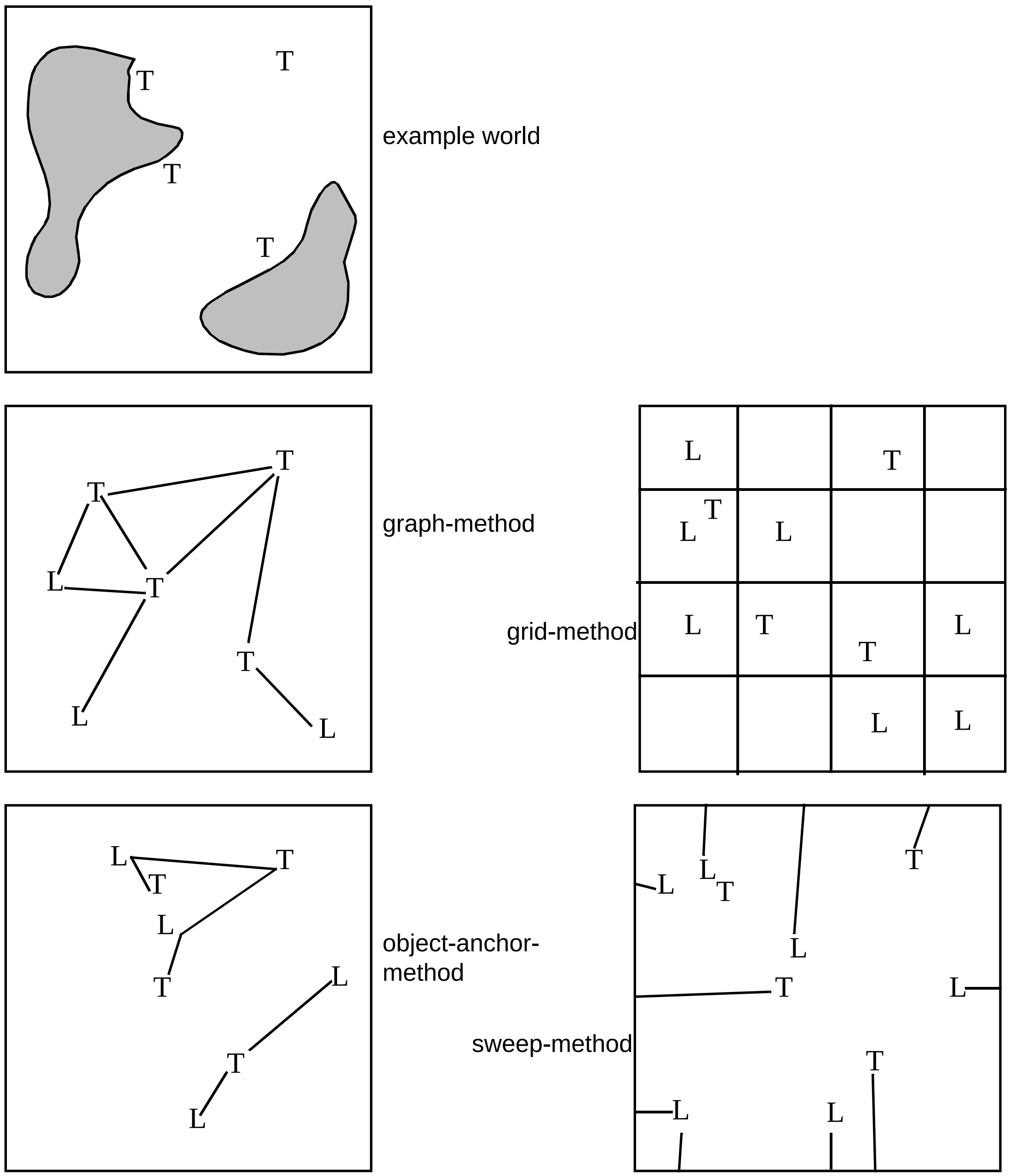

Figure 8-3 Examples of the spatial-memory representations observed. T designates targets. L designates land.

. **goal:** extent-method
. . . locate-any-edge
. . . **goal:** determine-direction-of-edge-method
. . . sweep-across-world-until-edge-intersected *; random direction using dead-*
. . . repeat-to-conclusion *; reckoning*
. **goal:** random-method
. . . random-paths-anywhere**]**

One of the more common search methods was to locally search first around the home target, then around located targets, and lastly land masses. In many cases, the targets were placed sufficiently far apart to render this method somewhat ineffective. For each example shown in this section, the data is shown in its entirety in Appendix E. The subject number for each is given. See Figure 8-4. The lawnmower- method makes sweeping motions back

Figure 8-4 Example of the local-search-method. Notice that in this case, it has been combined with the edge-following-method. [Subject 10, Control]

and forth and across the world fitting information into a grid representation. However, the subject must first locate a corner (not necessarily trivial) from which to begin. See Figure 8-5.

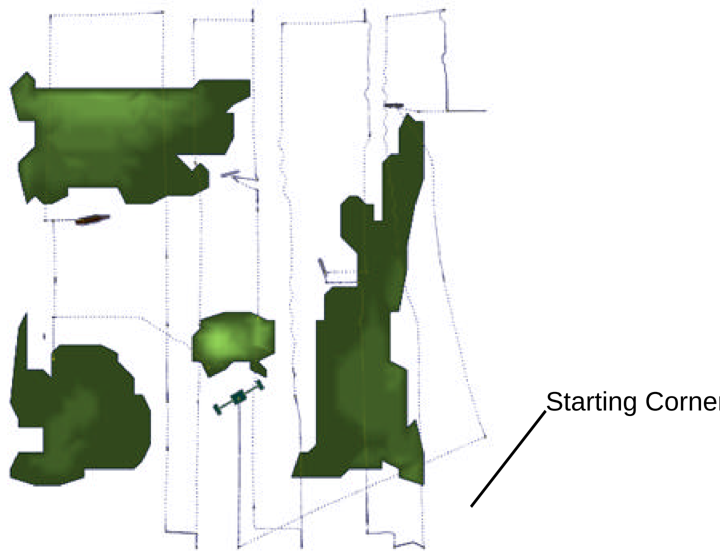

Figure 8-5 Example of the lawnmower-method. [Subject 4, Control]

By far the most common method was to routinely follow the edges of a land mass, searching the area around it (See Figure 8-4). During traversal, the land mass is maintained either to the left of the viewpoint (counterclockwise traversal) or to the right of the viewpoint (clockwise traversal). The most difficult part of this method was the need to locate a geographical landmark to mark the starting location of the circuit so that the subject would also know when to stop. Most subjects were unable to do this effectively and consequently traversed a single land mass several times. The other problem with this method is that land masses are often not close enough together to be able to move between them in this way.

In an attempt to handle this problem, an alternative was to traverse the land mass a number of times extending the distance from the coast with each circuit. A distinguishing characteristic of this behavior is that a track of the subject's movements will show a single line connecting land masses but multiple lines around each land mass. Again, this improves performance but does not necessarily allow subjects to reach all land masses. A heuristic may be used with this method intensifying the search in specific areas such as in bays or around a peninsula. A problem inherent to any coast following method is that as the coastline turns, the subject is rarely able to spatially perceive how much turn has taken place and therefore results in disorientation. See Figure 8-6.

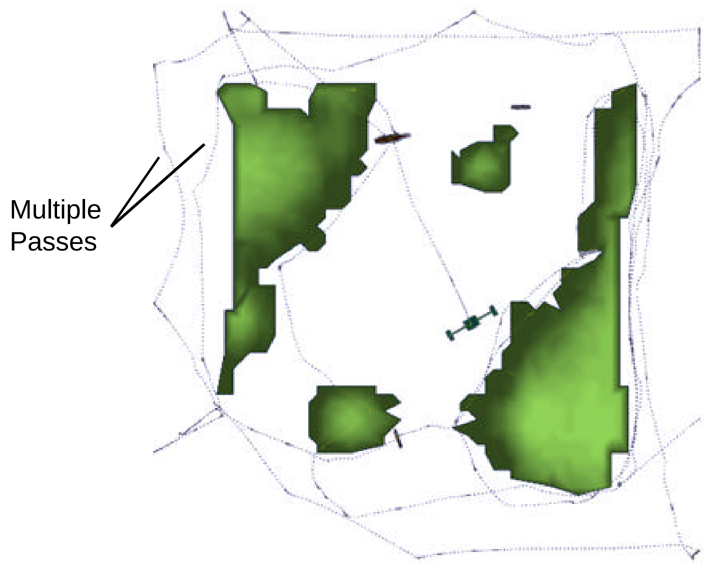

Figure 8-6 Example of the multi-pass-method. [Subject 9, Control]

Subjects searching the outer edges could use an extent method which involves moving across the world from edge to edge. This differs from the lawnmower-method in that it is less structured allowing movement from any edge to any other edge (See Figure 8-7). Finally, if all else failed, subjects fell into a random search which always led to disorientation in this treatment. This being the case, the subject may never return to an actual search but may spend the remainder of the task attempting to orient by some method.

A behavior observed in most trials is one which is intended to broaden the width of the field of view. The apparatus has a relatively low field of view (as compared to normal vision). Most subjects believed that their chances of missing a target in their peripheral vision was very high and therefore attempted to remedy this. The solution was to weave the viewpoint back and forth while moving. It is described as follows. See also Figure 8-3.

goal: field-of-view-stretching *; works forward or backward*
. viewpoint-weaving-during-movement

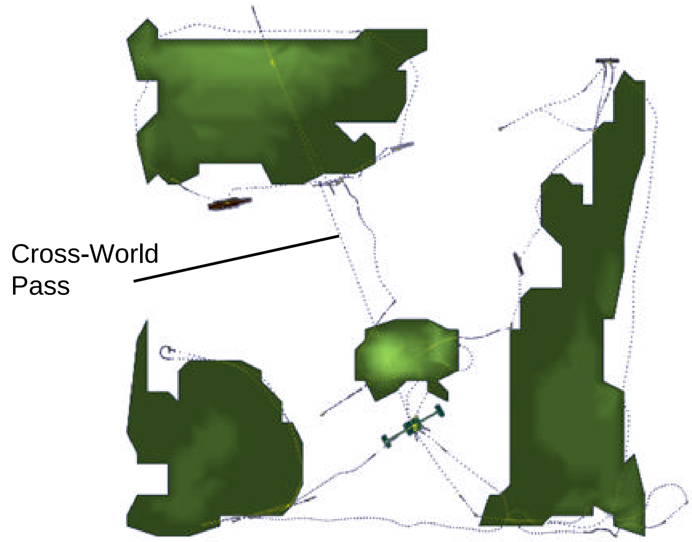

Figure 8-7 Example of the extent-method.
[Subject 8, Control]

As with the naive search, the selection of primed search is based on the mental representation being used. Subjects employing the graph representation might use a form of link traversal to retrace their steps if possible. If their representation was particularly strong, they may attempt to infer the actual direction to the home target in order to take a short-cut. But this would require very accurate and complete knowledge of the space. Subjects using the object-anchor-method (edge-following search) usually attempted to move directly to the home target and subsequently, most became disoriented. In the case of disorientation, the search becomes a naive search. The subject using the grid-method moved in a manhattan distance form as he referenced the world in terms of how far “up and over” he had moved.

goal: primed-search
. **[select goal:** link-traversal-method ; *associated with graph-method*
. . . retrace-paths-through-targets-to-home ; *non-optimal path*
. **goal:** inferred-direction-method ; *a short-cut method*
. . . infer-direction-to-home ; *requires accurate directional*
. . . direct-path ; *knowledge*
. **goal:** manhattan-distance-method ; *associated with lawnmower -*
. . . move-along-grid-to-home**]** ; *method*

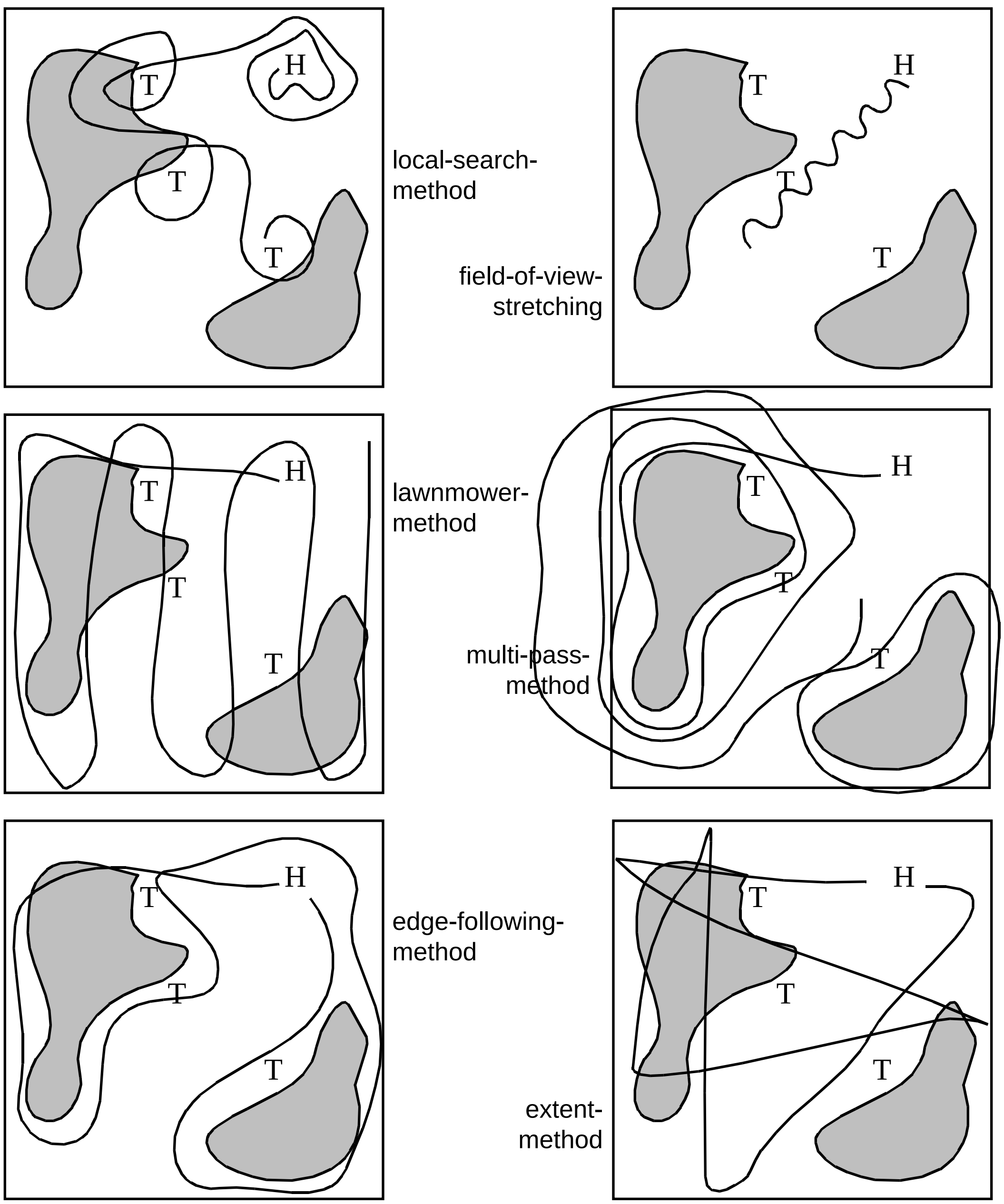

Figure 8-8 Examples of naive-searches. T designates targets. H designates the home target.

Discussion

In the control treatment, the subjects’ ability to comprehend and maintain orientation and position information was severely limited. Subjects were observed to depend on relatively weak cues such as the world’s extents or the sea texture in order to glean directional information. Consequently, these methods are fragile and commonly require the subject to reacquire the lost information. This is generally true for all methods in all treatments which are dependent on relative information rather than absolute information. However, as is illustrated in the grid treatment (See The Grid Treatment on page 156), relative methods can be highly functional. Unlike the control treatment where many subjects spent more time in position and orientation reacquisition than in target searching, the structure imposed on the world by the grid significantly improves the subjects’ ability to comprehend and cognitively organize the space.

A common mistake made particularly in the control and grid treatments was that subjects would not revisit targets located while they were disoriented. As stated earlier, a target located while the subject is disoriented cannot be accurately placed in the map drawing exercise. A better method would be for the subject to first reorient, then relocate any targets which may have been coincidentally “found” during reorientation.

A complication present in all treatments was the fact that as subjects proceed through a trial and turn their head continually, they eventually reach the maximum twist of the BOOM display which is restricted from further turning by a nylon binding. When this occurred, the subject had to either turn all the way around to release the tension, or (the recommended solution) step back from the display and return it to its normal position. This often was a cause of disorientation which had to immediately be repaired before the trial could proceed.

The subjects who performed the poorest on the control treatment were those who selected methods of task execution and subsequently changed the method or worse yet, violated the method’s execution. For example, several subjects choosing the edge-following-method crossed over the land during traversal allowing themselves no chance to integrate the shape or size of the land mass into their mental representation. In many cases this also caused them to become confused as to what direction they were travelling around the coast. One particular subject changed search strategy three times during execution. By the end of the trial it was nearly impossible to determine what had transpired. An important note to make concerning strategy is this;

> **There is no relationship between a subject conceiving of an effective strategy for execution of a task and the actual execution of that strategy.**

Most of the strategies described in this chapter, if properly carried out, would allow completion of the task. The execution may not be optimal, but it would be possible. It is conceivable that subjects underestimated the difficulty of the task. However, each subject attempted a practice trial which was identical to the control treatment beforehand so this is unlikely. It is more probable that subjects became discouraged or dissatisfied with their progress during execution and consequently switched methods in hopes of improved performance. This type of behavior was not only present in the control treatment but in all treatments collectively.

Lastly, two of the ten subjects[†] suffered from dizziness and motion sickness during the control treatment and had to stop before completion of the task. While there is no intention to investigate this phenomenon in this experiment, it is likely that disorientation, being a known precursor to motion sickness (DiZio & Lackner, 1992; Hettinger & Riccio, 1992; McCauley & Sharkey, 1992; Pausch, Crea & Conway, 1993), was the cause. These occurrences were in the control treatment only and the associated performance level of the subjects in question was among the lowest in the treatment.

The Grid Treatment

While all of the strategies employed in the control treatment were equally available in the grid treatment, the presence of the grid strongly influenced the selection criteria and more importantly, introduced many methods unavailable in the control treatment.

† Both were women.

```
goal: acquire-orientation
. [select goal: set-bearing-to-nearest-post-method
. .         [select goal: local-to-post-method
. . .               . small-movements-until-post-
                          visible
. .         .       goal: distance-to-post-method
. . .               . traverse-grid-to-post]        ; ring or radial
. .       . move-out-radial-to-outer-post           ; if post is red (no direction)
.         goal: set-bearing-default-method          ; must agree with post method
. .       . orient-with-default-view-direction
. .       . initial-view-direction-is-north
. .       . match-to-colored-post                   ; what post is north?
. .       . post-used-as-reference]                 ; for future references
```

Because the grid was known to be aligned with the world in a way analogous to the cardinal directions, most subjects chose to orient with respect to a north-south/east-west system. Subjects made small local movements relative to the home target while looking for a post. If this method failed to produce a post, the next alternative was to traverse the grid lines (either radials or rings) until a post was found. The distance between grid markings was such that this method would always succeed. If the located post was red (the center post), the subject would find it necessary to traverse a radial line in order to find a second post which contained directional information.

Subjects also aligned the world with the initial view direction as in the control treatment. In this case, however, they resolved this orientation with that of the grid. Using the initial view direction as north, this would be checked against the grid by determining which post marked that direction. Subsequently, the post would be used to reorient and maintain orientation.

```
goal: acquire-position
. [select goal: relative-to-post-method
. .       . goal: dead-reckoning-method
. .       . infer-distance-from-post
.         goal: relative-to-rings-method            ; approximate method
. .       . mark-which-ring-is-closest              ; range but not distance
.         goal: within-area-method                  ; divide world into parts
. .       . [select goal: pieslice/radius-method    ; place position within a
. . .               . nearest-ring-indicates-range  ; range/bearing segment
```

```
. . .           . posts-and-radials-indicate-bearing
. .     .       goal: quadrant-method               ; less refined than above
. . .           . nearest-ring-indicates-range
. . .           . posts-indicate-quadrant]
.       goal: relative-to-home-method
. .     . goal: dead-reckoning-method
. .     . infer-distance-from-home-target]
```

As with orientation, the grid was used extensively in obtaining position information. The most common method was to dead reckon to the nearest post since movement to a post was also a common orientation method. A less precise method was to position relative to the grid rings alone. This provides range information (distance from the center of the world) but not bearing. If this method is used, the subject must rely heavily on maintenance of orientation throughout the trial. Often, the nearest grid line was used as a path to traverse in order to complete the primed search.

A more precise refinement of this method is to place the home target within some bounded area of the world. Grid markings are used as the borders. The radials can be used to bound eight “pie slices” with the rings dividing each slice into three parts. A less precise alternative is to use the posts to define four quadrants. Rings can be used for range information as before. Lastly, dead reckoning from the home target itself can be used as in the control treatment. However, this is unlikely since even a relatively weak use of the grid is less error prone than a dead reckoning method which does not use the grid markings.

```
goal: reacquire-orientation
. [select goal: set-bearing-to-nearest-post-method   ; must remember post colors and
. .       . move-to-white-line                       ; orientation
. .       . traverse-white-line-to-next-post
.         goal: set-bearing-to-target-method         ; if orientation of target is known
. .       . bring-nearest-target-into-view
. .       . orient-with-respect-to-target]
```

Basing their mental representation of the space on the grid markings, if orientation was ever lost, subjects need only locate an outside post to reacquire it. This requires that the subject remember the colors of the posts at each cardinal direction. The rings were close enough together so that they could be located with ease. Also, the curvature of the rings was easily determined indicating which direction to travel in order to move inward or outward from the red inner post.

Subjects who did not depend on grid markings or could not remember the orientation of the posts had to rely on methods similar to those of the control treatment. One is listed here, that of orienting with respect to a known target. Notice that land is not used for directional information in this treatment. The reason for this is that subjects learned in their practice trial that the land did not provide effective landmarks for directional use and therefore used the far more efficient method of the grid markings instead.

In general, the grid assisted subjects enough that they did not require frequent reacquisition (as compared to the control treatment). Subjects ran into trouble primarily in the regions between posts most often because they did not closely watch and/or understand the grid markings during movement. A subject who did not count radial line crossings while following a ring, for example, would likely need to eventually return to a post in order to determine how far around the ring he had travelled.

```
goal: reacquire-position
. [select goal: relative-to-post-method
. .       . goal: dead-reckoning-method
. .       . infer-distance-from-post
.         goal: relative-to-rings-method           ; approximate method
. .       . mark-which-ring-is-closest             ; range but not distance
.         goal: within-area-method                 ; divide world into parts
. .       . [select goal: pieslice/radius-method   ; place position within a
. . .             . nearest-ring-indicates-range   ; range/bearing segment
. . .             . posts-and-radials-indicate-bearing
. .       .       goal: quadrant-method            ; less refined than above
. . .             . nearest-ring-indicates-range
. . .             . posts-indicate-quadrant]
.         goal: relative-to-target-method
. .       . goal: dead-reckoning-method
. .       . infer-distance-from-target]
```

For this treatment, the subtask of reacquiring position is almost identical to that of its original acquisition. Specifically, the posts are the primary source. Subjects, when lost, return immediately to the nearest post. The other methods are equally similar as subjects use the method most closely aligned with their mental representation. The primary difference in these cases is that the task does not necessarily begin at the home target or at any specific place at all. As before, positioning relative to a target is rare and is used only if the subject knows the target's orientation and if this method is thought to be significantly more convenient than the others.

```
goal: maintain-orientation
. [select goal: move-to-nearest-outer-post-method      ; not the inner post
. .        . move-to-white-line
. .        . traverse-white-line-to-next-post          ; only need to see it
.          goal: count-radial-crossings-method         ; used with ring traversals
. .        . each-radial-is-1/8-circumference          ; necessary to count
. .        . enter-new-pieslice-each-crossing
.          goal: move-target-to-target-to-post-method  ; used with graph representation
. .        . move-between-targets-and-post(s)
. .        . align-targets-with-post]
```

The most effective method of maintaining orientation was to frequently pass within view of an outer post so that the subject would remain aligned with the world. Knowing that the outer posts reside on the white ring, the subject need only use this information to locate the nearest post. There is no need to actually move all the way to the post, rather only so that it comes into view. Also, the inner post is not suitable for this task since it does not indicate direction.

Another method is to count each crossing of a radial line in order to determine which pie slice the subject was currently within. There are eight wedges in the world requiring that the subject mentally count along the traversal. This method can be more efficient than the post method since it requires less movement but it is more cognitively demanding detracting from the primary cognitive task.

Subjects could also attempt to form a triangle between two targets and a post which works well when used with the mental graph representation described earlier. Targets can be aligned with the post to correctly orient them and the observer in the world. However, the distances between targets and posts was most often too great for this technique to be used with any regularity.

```
goal: maintain-position
. [select goal: move-to-nearest-post-method          ; if red, only if oriented
. .          . move-to-white-line
. .          . traverse-white-line-to-next-post      ; only need to see it
.            goal: move-to-nearest-ring-method       ; only if oriented
. .          . move-to-radial-line
. .          . traverse-radial-to-ring
.            goal: ring-crossing-method              ; used with radial traversals
. .          . each-ring-is-range-to-posts           ; not necessary to count
. .          . enter-new-area-each-crossing
.            goal: move-target-to-target-to-post-method   ; used with graph representation
. .          . move-between-targets-and-post(s)
. .          . goal: dead-reckoning-method]
```

While maintaining orientation, most subjects also determined their current position and that of the targets. Most commonly, this was done using the outer posts. However, unlike maintain-orientation, the red post could be used if the subject knew the orientation but not the range. Similarly, the rings could be used as long as directional information was not needed.

Following a radial line, the subject needs only the position relative to the colored rings to know the current position. There is no need to count these as there was for the radial lines because of the color coding on the rings. This method requires a higher cognitive workload to maintain. Lastly, the subject may dead reckon between targets and posts. As was the case for maintain-orientation, this method is appropriate only for the rare cases where multiple targets and posts are visible from a single vantage point.

```
goal: spatial-memory                                 ; how spatial info is memorized
. [select goal: graph-method                         ; similar to control treatment
. .          . located-targets-as-nodes
. .          . posts-as-nodes
. .          . paths-between-targets/posts-as-edges
.            goal: radial-grid-method
. .          . [select goal: pie-slice-method
. . .                  . eight-wedges
. . .                  . four-regions-each-wedge
. .          .         goal: quadrant-method         ; ignore the diagonals
. . .                  . four-wedges
. . .                  . four-regions-each-wedge
```

. .   .   **goal:** concentric-ring-method
. . .   . four-regions
. . .   . one-center
.   **goal:** object-anchor-method   *; associated with edge-following*
. .   . targets-located-relative-to-land
. .   . land-located-relative-to-posts**]**

The graph method used in the control treatment can still be used in the grid treatment but there is extra information to include. The posts are most often included in the representation itself. This is clearly indicated by the fact that nearly all subjects drew the grid on their map exercise in order to place targets and land masses relative to it.

The grid was designed so that it would have an effect on subjects' conception of the space but that the effect would not be known specifically. In other words, there are many ways to view the radial grid markings and divide the world accordingly. The three methods observed in the experiment are described in Figure 8-9. The radial lines divide the world into eight wedges of equal size. Each wedge is further divided by the colored rings. This can be somewhat simplified by dropping the diagonal radials in order to view the world as four quadrants. Finally, the world can be divided into four circular regions as defined by the rings only.

The use of the edge-following-method of search was so predominant throughout the treatments across subjects that many subjects, even when given a cue such as the grid, developed ways to continue with this method. This may be a case of "sticking with what works" rather than chance a different (although possibly better) approach. Consequently, subjects continuing to traverse coastlines attempt to place targets relative to the land masses as before. However, the grid does appear as a method of placing the land masses themselves. The resulting map sketches are improved over the control treatment (See Appendix E).

goal: naive-search
. **[select goal:** path-traversal-method   *; grid markings as paths*
. .   **[select goal:** ring-method
. . .   . traverse-color-rings
. . .   . use-posts-as-reference

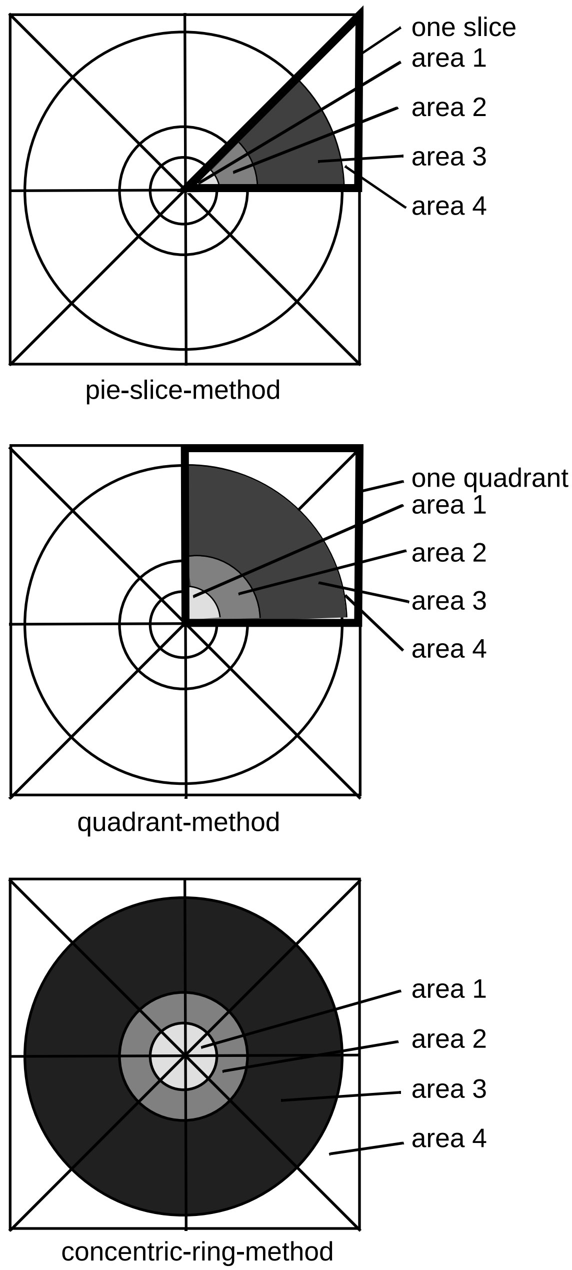

Figure 8-9 Pictorial description of the three predominant conceptual spatial representation used during the grid treatment.

. . . **goal:** radial-method
. . . . traverse-black-radials
. . . . use-posts/rings-as-reference**]**
. **goal:** area-search-method *; goes with spatial memory*
. . **[select goal:** pieslice-method
. . . . traverse-extents-of-each-wedge
. . . . number-memorization *; see description of code*
. . . **goal:** quadrant-method
. . . . random-search-within-area *; may traverse lines*
. . . **goal:** concentric-ring-method
. . . . weaving-search-between-rings**]**
. **goal:** edge-following-method
. . . locate-land-mass
. . . **[select** select-geographical-landmark-on-coast
. . . use-posts-as-reference**]** *; more common*
. . . traverse-edge-to-completion
. **goal:** local-search
. . . search-space-local-to-targets
. . . search-space-local-to-posts
. **goal:** random
. . . random-paths-anywhere**]**

Although it was not anticipated as a possible use, the grid markings were often used as paths to be traversed. Both the rings and the radials and combinations of the two were used in this way. But this method only guides the search, it does not necessarily structure it. By dividing the world into areas which are logically connected and organized, the subject is better able to not only locate the targets but also to place them in a mental representation. The three methods described here coincide with the three forms of representation described under spatial-memory.

Only one subject divided the world into pie slices. Starting at the green post (which was designated as north), the subject searched the area of each slice in turn from the inside to the outside and back again. The wedges were ordered in a counterclockwise manner. Each wedge was further divided by the rings. A three digit code sequence was used by this subject to place each target spatially. In the example in Figure 8-10, target 1 would be designated by the code 1-3-1. The target number is 1, the ring area is 3, and the wedge num-

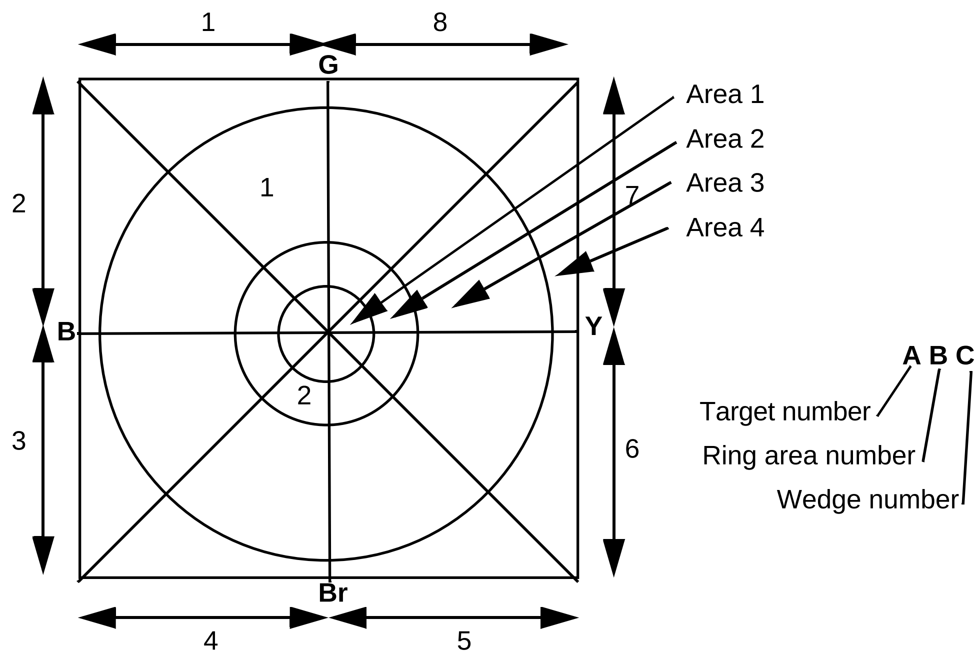

Figure 8-10 The three digit code used with the pie-slice-method.

ber is 1. Similarly, target 2 would be coded as 2-2-4. The difficulty with this method is that while it is highly structured and accurate, the subject must remember 18 numbers (3 for each target, 6 targets). Furthermore, this does not include any information relevant to the land masses. But while this method places extreme cognitive demands on the subject, it must be noted that this subject drew a highly accurate map. See Figure 8-11.

Other approaches to dividing the world included a quadrant method and a concentric ring method. Both of these incorporated a search within the sub-areas of the world which may be random in nature. This is an effective technique provided that the area in question is not a large-scale space as defined in Definition of Terms on page 6. Rather than search randomly within a sub-area, subjects using the concentric-rings-method tend to weave back and forth between rings while moving around the circle.

Many subjects continued to use a coastline following method of search. This was very similar to the technique described in the control treatment except that rather than use geographical landmarks to guide the traversal (this was shown to be ineffective in the control treatment), most subjects used the outer posts as reference points.

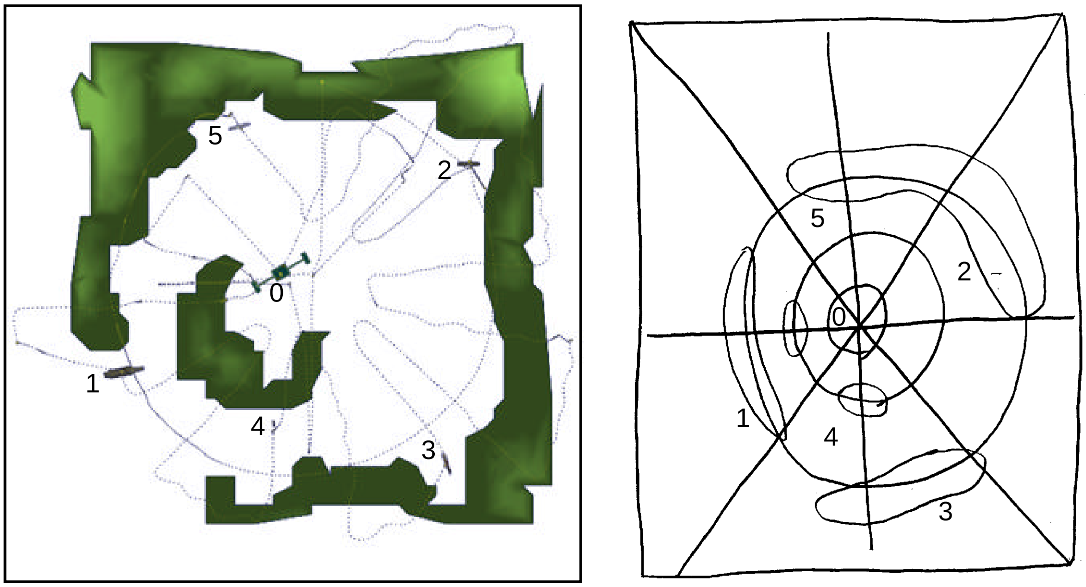

Figure 8-11 The path chart and drawn map from the area-search-method. [Subject 4, Grid]

Local and random searches were also observed in this treatment but were relatively rare. In using a local search, posts were used as reference points as well as targets and the home target. A random search would only occur if the subject failed to remember the orientation of the markers.

goal: primed-search
. **[select goal:** grid-approximate-method *; most common method*
. . . follow-grid-lines-until-seen
. **goal:** grid-accurate-method *; only if home near a post*
. . . infer-direction-to-nearest-post
. **goal:** infer-direction-method
. . . direct-path-to-home**]**

Subjects placed the home target in their cognitive map in a number of ways. In the approximate method, the subject notes that the home target lies near a particular grid line. To return to it, the subject need only locate the appropriate marking and follow it until the target is seen. A more accurate method is based on the posts rather than the lines. The subject infers the direction of a particular post which is known to lie near the home target. On approaching the post, the home target is found. Lastly, a few subjects were able to infer the direction of the target itself rather than a grid marking near it. This technique is the most efficient method if successful but it is also the most error prone.

Discussion

Subjects tended to use the grid instead of land or targets for orientation/position information but still relied heavily on coastlines for searching. In fact, one subject complained that the grid markings were a distraction while traversing a coastline. There were a number of “false alarms” where the subject mistook a grid marking for a target. This was also true in the map/grid treatment. The grid was often not used for actual navigation but rather only as a reference for spatial memory.

Subjects were also observed to frequently stop and start more often in this treatment than the others. The added information, while enabling more efficient search strategies than the control treatment, forced subjects to explicitly encode spatial knowledge. This is also discussed in Average Velocity on page 123.

Many subjects followed a specific search technique only until a target was located, at which time the method was violated immediately. For example, while traversing a coastline, a subject noticing a target off the opposite bank of a narrow stretch of land would tend to violate the principle of the edge-following-method and cross the land to identify the target. Although this may not seem significant, these subjects often were unable to pick up where they left off thus leaving large tracts of space unsearched.

It was interesting to note that subjects often wanted to use the grid lines as paths. One subject verbally stated how much the black radial lines looked like a road. This phenomenon suggests that subjects prefer, and in some cases require, that movement be either restricted or at least guided in some fashion in order to effectively eliminate the possibility of total disorientation within a large world. This hypothesis fits neatly into the framework of this research which asserts that large spaces be divided into smaller, connected parts thus potentially adding structure to an otherwise amorphous environment. This is further supported by the increased performance of subjects on the grid treatment over the control treatment.

The Map Treatment

The use of a map offers a top-down or third-person view of the environment. The primary value added in this treatment is a source of absolute spatial information which is always immediately available making orientation and position subtasks essentially trivial. Furthermore, the global view enables the use of geographical landmarks which are difficult to perceive from a first-person, perspective view. These facts will be evident in the methods subjects used within this treatment.

goal: acquire-orientation
. **[select goal:** set-bearing-default-method *; commonly used*
. . . orient-with-default-view-direction
. . . obtain-direct-from-map
. . . initial-view-direction-is-north *; assume cardinal directions*
. **goal:** set-bearing-to-edge-method
. . . pick-an-edge-of-the-map
. . . identify-edge-as-north *; assume cardinal directions*
. **goal:** set-bearing-to-geographical-landmark *; often used with one of above*
. . . orient-toward-geographical-landmark**]**

Although this first method seems from the surface to be identical to the set-bearing-default-method described in the control treatment, it differs significantly due to the global view provided. Subjects most often used the initial view direction as the default north. The edge identified as north is directly obtained from the map rather than relative to some object as it was previously done.

Alternatively, some subjects twisted their viewpoint around in several directions before orienting. Consequently, they simply chose an arbitrary edge as north in their mental representation. This is clearly supported by the orientation of the drawn maps from these subjects.

Lastly, and often in concert with other methods, subjects used geographical landmarks to help differentiate one edge from another. This might include the overall orientation and position of the land masses themselves or merely the placement of a bay or peninsula relative to an edge.

goal: acquire-position
. **[select goal:** relative-to-geographical-landmark
. . . use-same-landmark-as-in-orientation
. . . obtain-position-direct-from-map
. **goal:** relative-to-edges-method
. . . estimate-from-two-adjacent-edges
. . . obtain-position-direct-from-map**]**

Using the same landmark or land configuration as in acquire-orientation, the subject may obtain position information directly from the map. This same technique can be accomplished using the map edges as guides for future reference. Whatever method is chosen, the execution of this subtask is trivial since the viewpoint position is represented on the map itself.

goal: reacquire-orientation *; rarely necessary*
. **[select goal:** set-bearing-to-edge-method *; no movement required in*
. . . identify-north-edge *; any method*
. . . orient-to-edge
. **goal:** set-bearing-to-geographical-landmark
. . . orient-toward-geographical-landmark**]**

goal: reacquire-position *; rarely necessary*
. **[select goal:** relative-to-geographical-landmark *; no movement required in*
. . . use-same-landmark-as-in-orientation *; any method*
. . . obtain-position-direct-from-map
. **goal:** relative-to-edges-method
. . . estimate-from-two-adjacent-edges
. . . obtain-position-direct-from-map**]**

Both of the reacquisition subtasks are rarely, if ever, necessary. In fact, the only way they could be needed would be if the subject somehow became confused as to the orientation scheme identified in initial acquisition. For example, the subject may mistake the edge assigned to north or the land mass nearest a particular edge. The methods of reacquisition are similar, if not identical, to the acquisition methods; the only difference being that reacquisition does not necessarily commence at the home target. Either land masses and geographical landmarks or map edges are used to identify a north edge.

goal: maintain-orientation
. keep-map-in-view
. observe-map-orientation
. align-with-world**]**

goal: maintain-position
. keep-map-in-view
. observe-viewpoint-marker-position
. align-with-world**]**

As with acquisition, maintenance subtasks are trivial in nature as all necessary information is available immediately and in absolute form from the map. Therefore, only one method is provided here, as it is the only method used by all subjects in the experiment. The subject will keep the map in view at all times while moving. This is accomplished by not allowing the view direction to point too high so as to crop the map from the viewplane. The subject will intermittently look down at the map while scanning the world for targets to check the current orientation and position. If necessary, these are then compared to the actual world if alignment is required.

goal: spatial-memory
. **[select goal:** object-anchor-method
. . . targets-located-relative-to-geographical-landmarks
. **goal:** graph-method
. . . located-targets-as-nodes
. . . paths-between-targets-as-edges
. **goal:** grid-method *; associated with lawnmower-*
. . . world-to-cartesian-space *; method*
. . . targets-mapped-absolutely**]** *; conceptually up/down/across*
. land-mapped-absolutely

The methods used to represent spatial information in memory in the map treatment are very similar to those observed in the control treatment. As before, the chosen method is typically related to the type of search method employed. The most common method was that of placing targets in relation to land configurations. This was far easier in this treatment than in the control treatment as geographical landmarks were readily available. Less common was the graph and grid methods which were used as described earlier. However, both of these were more accurate due to the ability of the subject to place targets in absolute positions in the world. In all cases, the land was mapped in terms of its absolute position in the environment.

An interesting behavior associated with the map and the map/grid treatments was that many subjects (not all), upon locating a target, would turn the viewpoint so that the map was aligned with its original orientation. Although this behavior in itself does not allow a definitive conclusion to be drawn regarding mental representation, it is indicative of an orientation-specific mental representation. This topic will be discussed in detail in the next chapter.

goal: naive-search	
. **[select goal:** local-search-method	
. . . search-local-space-to-target/landmark	*; for each target found*
. **goal:** lawnmower-method	
. . . locate-any-corner	*; directly from map*
. . . move-across-world-to-opposite-edge	*; one up-down sweep*
. . . move-across-world-one-step	*; one step = view depth*
. . . repeat-until-entire-world-searched	*; optimized for map*
. **goal:** edge-following-method	*; single circuit*
. . . locate-land-mass	
. . **[select goal:** large-object-method	
. . . . select-geographical-landmark-on-coast	*; not always necessary*
. . . . traverse-edge-until-landmark-revisited	*; one time around*
. . . **goal:** small-object-method	
. . . . move-to-land-mass-center	
. . . . stop-movement	*; no movement required*
. . . . view-edges**]**	
. **goal:** heuristic-method	*; often used with other methods*
. . . intensify-search-around-points-of-interest	
. **goal:** random-method	
. . . random-paths-anywhere**]**	

In many ways, search techniques were greatly improved by the presence of the map. The lawnmower-method was again used in a similar fashion to that described in the control treatment, however the path traced by the subject was optimized for the terrain. Since targets were not to be found over land, the subject would break off the search as it intersected land (See Figure 8-12).

Edge following was also greatly improved as subjects no longer would traverse land masses multiple times because they lost their starting point. Geographical landmarks were clearly identified on the map making this a trivial task. However, landmarks were not always necessary. The subject could determine the approximate starting position based on a point on a circle (e.g. starting position at approximately three o'clock on a particular land mass). A slightly different method for small land masses allowed the subject to fly over the center of the island and search the edges from a single position rather than traverse the edge. Used along with these types of search was a highly effective heuristic search. Several subjects would intensify their search in areas they thought would most likely hide a ship target. Specifically, they would first search near points of interest such as bays and oddly-shaped land formations (See Figure 8-12).

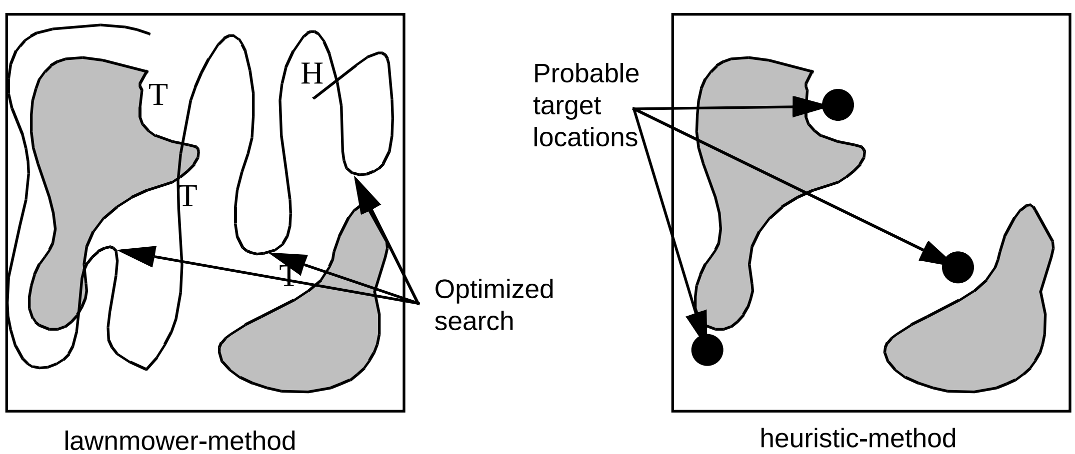

Figure 8-12 The lawnmower and heuristic methods as observed in the map treatment.

Lastly, the local-search and random methods were also observed in some subjects' behavior. Local searches involve movement relative to a target or landmark. Random searches are observed to be unstructured movement within a confined area for a specific period of time.

goal: primed-search
. **[select goal:**direct-method ; *a short-cut method*
. . . direct-path-to-home ; *direct from map*
. **goal:** local-landmark-method ; *could be land or edge*
. . . direct-path-to-landmark-near-home
. . . direct-path-to-home**]**

Since the ability to maintain orientation and position are trivialized by the map, the primed search is also very simple as compared to non-map treatments. The method used depends on how the subject mentally placed the home target as orientation and position were being acquired at the beginning of the treatment.

The most obvious method would require that the subject know the exact position of the home target in order to move directly to it. If the exact position is known, this is not difficult. However, most subjects placed the home target relative to some visible marking such as the land masses or an edge. The primed search was then completed by moving directly to the "virtual" target which is known to be local to the home target, and then finally homing when the target comes into view.

Discussion

In many ways, the map allows the strategies of the control treatment to be executed more effectively. In some cases, this meant that the strategy became tractable (implying that it was intractable in the control treatment); in others it meant that optimizations were made. In addition to providing a geocentric point of view, the map adds some information previously unavailable. The edge of the map can be used for navigation as well as geographical landmarks which were needed for many of the control treatment search techniques.

This was the preferred treatment of most subjects when questioned after completing all trials. The dominance of the edge-following-method of search and its suitability to this treatment support this. However, as was shown in the ability to infer direction (See Map Direction Error on page 127), the preferred method is not always the best.

The Map/Grid Treatment

The addition of the grid superimposed atop the map and in the world itself introduces new methods available for wayfinding tasks. Of particular interest in this treatment is the effect of the grid on the methods described in the map treatment or, conversely, the effect of the map on the methods described in the grid treatment. The map/grid treatment, being a combination of the map and the grid treatments shows similarities to both.

goal: acquire-orientation
. **[select goal:** set-bearing-default-method ; *commonly used*
. . . orient-with-default-view-direction
. . . obtain-direct-from-map
. . . initial-view-direction-is-north ; *assume cardinal directions*
. . . align-with-posts
. **goal:** set-bearing-to-edge-method
. . . pick-an-edge-of-the-map
. . . identify-edge-as-north ; *assume cardinal directions*
. . . align-with-posts
. **goal:** set-bearing-to-geographical-landmark ; *often used with one of above*
. . . orient-toward-geographical-landmark
. **goal:** set-bearing-to-posts
. . . select-post-as-north**]**

The methods of acquiring orientation used in the map treatment are also present here but there is always an added step; that of aligning the view direction with the grid and posts. In other words, once identifying a particular edge as north, the subject will further mark this fact with the colored post associated with that edge.

goal: acquire-position
. **[select goal:** relative-to-geographical-landmark
. . . use-same-landmark-as-in-orientation
. . . obtain-position-direct-from-map
. **goal:** relative-to-edges-method
. . . estimate-from-two-adjacent-edges
. . . obtain-position-direct-from-map
. **goal:** relative-to-post
. . . estimate-distance-to-nearest-post
. . . obtain-position-direct-from-map
. **goal:** relative-to-rings
. . . estimate-which-ring-is-closest ; *range but not distance*
. . . obtain-position-direct-from-map

```
.        goal: within-area-method                     ; divide world into parts
. .      . [select goal: pieslice/radius-method       ; place position within a
. . .              . nearest-ring-indicates-range     ; range/bearing segment
. . .              . posts-and-radials-indicate-bearing
. .      .         goal: quadrant-method              ; less refined than above
. . .              . nearest-ring-indicates-range
. . .              . posts-indicate-quadrant]
. .      . obtain-position-direct-from-map]
```

The acquire-position methods are all dependent on the visible markings on the map. This, of course, includes the grid markings in a similar fashion to that described in the grid treatment. In all cases, the map is used to access the desired information directly rather than having to infer it from movement as was the case in the grid treatment. Also notice that the area descriptions present in the grid treatment are also present here. These will be used later in the methods for search.

```
goal: reacquire-orientation                           ; rarely necessary
. [select goal: set-bearing-to-edge-method            ; no movement required in
. .      . identify-north-edge                        ; any method
. .      . orient-to-edge
.        goal: set-bearing-to-posts
. .      . identify-north-post
. .      . orient-to-post
.        goal: set-bearing-to-geographical-landmark
. .      . orient-toward-geographical-landmark]

goal: reacquire-position                              ; rarely necessary
. [select goal: relative-to-geographical-landmark     ; no movement required in
. .      . use-same-landmark-as-in-orientation        ; any method
. .      . obtain-position-direct-from-map
.        goal: relative-to-edges-method
. .      . estimate-from-two-adjacent-edges
. .      . obtain-position-direct-from-map
.        goal: relative-to-post
. .      . estimate-distance-to-nearest-post
. .      . obtain-position-direct-from-map
.        goal: relative-to-rings                      ; approximate method
. .      . estimate-which-ring-is-closest             ; range but not distance
. .      . obtain-position-direct-from-map
.        goal: within-area-method                     ; divide world into parts
```

. .   . **[select goal:** pieslice/radius-method   *; place position within a*
. . .   . nearest-ring-indicates-range   *; range/bearing segment*
. . .   . posts-and-radials-indicate-bearing
. .   .   **goal:** quadrant-method   *; less refined than above*
. . .   . nearest-ring-indicates-range
. . .   . posts-indicate-quadrant**]**
. .   . obtain-position-direct-from-map**]**

As with the map treatment, reacquisition is rarely necessary. The only cases where it was needed was when the subject made a mental error and became confused as to which edge had been designated as north. In these cases, the subject most likely returns to the very same method used to acquire orientation and position. However, this time the task is executed wherever the subject happened to be upon realization that disorientation had occurred.

goal: maintain-orientation
. keep-map-in-view
. observe-map-orientation
. align-with-world**]**

goal: maintain-position
. keep-map-in-view
. observe-viewpoint-marker-position
. align-with-world**]**

These are the same methods used with the map treatment. The only difference is in the "checkpoints" available for the subject to mark off during movement. The world and the map are most easily aligned by noting the concurrent passing of a landmark (geographical or grid marking) on the map and in the world. With the grid represented on the map, this is easier to do since there are more markings suitable for this purpose.

goal: spatial-memory
. **[select goal:** object-anchor-method
. .   . targets-located-relative-to-geographical-
               landmarks
. .   . land-located-relative-to-posts
.   **goal:** radial-grid-method
. .   . **[select goal:** pieslice-method
. . .   . eight-wedges

. . . . four-regions-each-wedge
. . . **goal:** quadrant-method *; ignore the diagonals*
. . . . four-wedges
. . . . four-regions-each-wedge
. . . **goal:** concentric-ring-method
. . . . four-regions
. . . . one-center
. . . targets-mapped-absolutely**]**

Conceptually, the world in this treatment can be divided in a form similar to the grid treatment or the map treatment depending on whether the grid markings or land masses are used as separators. If the grid is used, the world can be divided in the same ways as in the grid treatment; specifically, using the pieslice-method, the quadrant-method, or the concentric-ring-method. If the grid is not used, subjects place targets according to geographic landmarks as in the map treatment. In all cases, however, positions are marked in absolute terms rather than relative.

goal: naive-search
. **[select goal:** area-search-method *; goes with spatial memory*
. . **[select goal:** pieslice-method
. . . . traverse-extents-of-each-wedge
. . . . number-memorization *; see description of code*
. . . **goal:** quadrant-method
. . . . random-search-within-area *; may traverse lines*
. . . **goal:** concentric-ring-method
. . . . weaving-search-between-rings**]**
. **goal:** edge-following-method
. . . locate-land-mass
. . . select-geographical-landmark-on-coast *; not always necessary*
. . . traverse-edge-until-landmark-revisited *; one time around*
. . . **[select** select-geographical-landmark-on-coast
. . . use-posts-as-reference**]** *; more common*
. . . traverse-edge-to-completion
. **goal:** local-search
. . . search-space-local-to-targets
. . . search-space-local-to-posts
. **goal:** heuristic-method *; often used with other methods*
. . . intensify-search-around-points-of-interest**]**

The same area-search methods are available in this method as were available in the grid treatment. Notice that the cognitive overhead of heavy number memorization still applies but the path traversal is more organized and the drawn map is more accurate (See Figure 8-13). Many subjects stated that they did not use the grid for navigation during search. They simply used the same method used in the map treatment and ignored the grid. However, in review of the data, it was found that while this is primarily true, when targets were found using the edge-following technique, subjects would place them with respect to the grid markings and the posts. Consequently, maps drawn from the map/grid treatment were typically more accurate than those of the map alone.

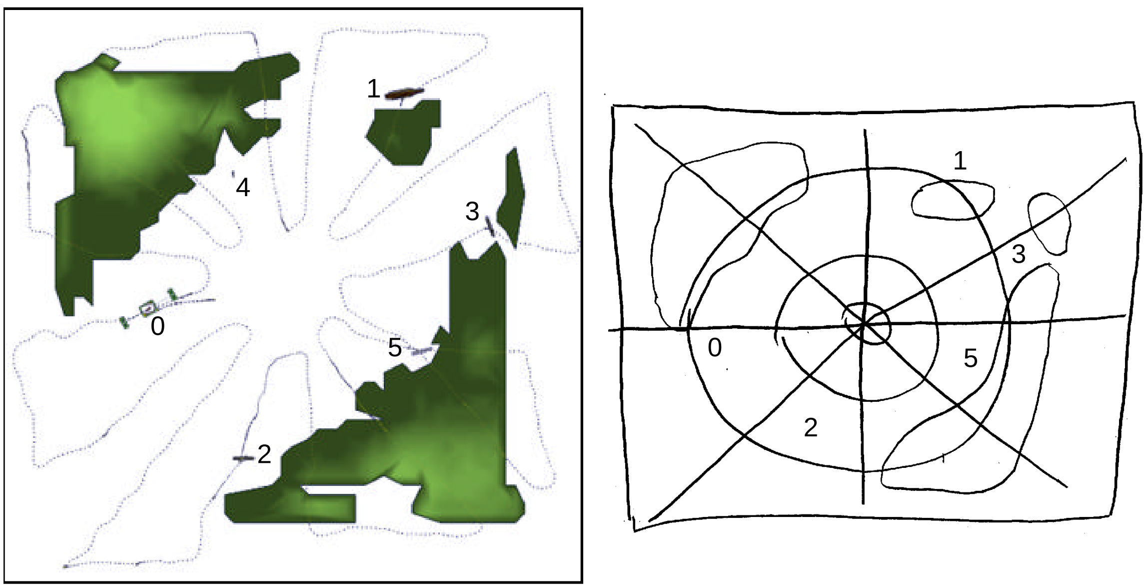

Figure 8-13 The path chart and drawn map of an area-search-method in the map/grid treatment. Compare to Figure 8-11 on page 166. [Subject 4, Map/Grid]

goal: primed-search
. **[select goal:**direct-method ; *a short-cut method*
. . . direct-path-to-home ; *direct from map*
. **goal:** local-landmark-method
. . . direct-path-to-landmark-near-home
. . . direct-path-to-home
. **goal:** grid-approximate-method ; *most common method*
. . . follow-grid-lines-until-seen
. . . direct-path-to-home
. **goal:** grid-accurate-method ; *only if home near a post*

. .   . move-direct-to-nearest-post
. .   . direct-path-to-home**]**

Because the map provided such a wealth of information to navigate by including reference points for marking targets, subjects most often moved directly to the nearest point of reference to the home target for the primed search. This could be either a local landmark, post, or grid line crossing. Other methods include the direct-method in which the subject homes directly to the home target position and the grid-approximate-method in which grid markings are traversed. These were less common because of the probability of error in the case of the direct-method, and inefficiency in the case of the grid-approximate-method.

Discussion

Subjects using the edge-following-method noted that the grid markings in the world were distracting at times. The implementation of the grid over the world contained an artifact of flashing in some cases. This flashing attracted the attention of the subjects and caused more misled searches than would have usually been the case.

In regards to the map in general, many subjects found it difficult to maintain altitude while using the map. The map, being a powerful aid to navigation, was relied upon heavily during movement. Subjects continually glanced down at it to verify position or orientation. Unfortunately, the locomotion scheme used in this experiment causes the movement direction to change with the view direction. Consequently, as the subject would be studying the map during movement, the viewpoint would eventually reach its minimum.